Blue Whale Behavioral Response Study & Field Testing of the New Bioacoustic Probe

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LONG-TERM GOALS

Task 1: Blue Whales Behavioral Response Study

The behavioral response of large whales to commercial shipping and other low-frequency anthropogenic sound is not well understood. The PCAD model (NRC 2005) for assessing sound impacts on marine mammals calls for studies on sound source characteristics and the behavioral impact of specific sources on individual animals. Our goal is to understand the vocal and behavioral response of individual blue whales to high-intensity ship noise and close ship approach, resulting from the close geographic association between known foraging grounds and commercial shipping lanes off

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California. To accomplish this goal we deploy acoustic recording tags and GPS recording tags on individual blue whales within and near the shipping lanes while concurrently monitoring shipping traffic using AIS.

Task 2: Field testing the new Bioacoustic Probe:
Tagging studies of odontocetes have yielded incredible insights into the diving, movement, and daily activities patterns of several species. Missing from most of these studies has been information on the acoustic environment in which the animal is living and the sounds produced by the animals during different activities. Our goal is to use the new Acousonde to initiate studies of beaked whale and other large odontocete whale species in the Pacific. Although our aim is to address several scientific questions relating to diving behavior, vocal behavior, and swimming mechanics with the data collected during these deployments, the primary goal of this project is to conduct first field trials of the Acousonde with several species of cetacean and to refine the operation of the tag for robust field operation in the future.

OBJECTIVES

Task 1: Blue whale behavioral response study:
Our specific objectives are the following:

(1) Do blue whales exposed to high-intensity ship noise or close ship approach change their calling or diving behavior?

(2) What is the form of the response (cessation of feeding, change in orientation, change in vocalization rate or intensity, change in swimming speed, etc.)

(3) Is there a threshold sound level that elicits a response by blue whales?

(4) How long does the behavioral reaction persist relative to the increased noise level?

(5) What are the potential energetic and social costs of any response to noise?

Task 2: Field testing the new Bioacoustic Probe
The target specifications of the Acousonde include maximum depth of 3000m, maximum sustained acoustic sample rate of 232kHz, storage of 8Gb, 2 channels of acoustic data, and 3-dimensional accelerometer and compass. Our primary goal is to evaluate the functionality of the tag when used with odontocetes and to begin collection of vocal and diving behavior on a wide variety of odontocete species.

APPROACH

Task 1: Blue whale behavioral response study:
We evaluate the behavioral response of blue whales to intense ship noise and close ship approach using suction-cup attached acoustic recording tags and GPS Fastlock location tags. The proximity of shipping routes into southern and central California ports with predictable blue whale feeding grounds makes this an ideal location of the study of the impact of intense low-frequency noise on whale behavior. Field effort has been conducted for project since 2008. Past effort focused on the Santa Barbara Channel where shipping lanes pass through areas of frequent use by blue whales. Ship traffic use of the channel changed after the California Air Resources Board (CARB) rules in late 2008

mandating use of cleaner fuels within 24 nmi of shore resulted in many ships abandoning the shipping lanes through the channel (Law 2009). At that time, predicting locations of ship and vessel interactions became more difficult. In 2010, we transitioned a portion of our operations to the shipping lanes off San Francisco near the Farallon Islands as predictable sightings of blue whales in the shipping lanes there made for an opportunity to work with both ships and whales. In 2011, we transitioned our southern California effort further south, just outside the ports of Los Angeles and Long Beach where vessels taking varied routes around the Channel Islands reconverge, though are generally travelling slower (12 knots) than in areas further from the ports (Figure 1).

Ship locations are monitored using a real-time AIS receiver installed aboard the tagging boat and from two shore stations, one on the campus of University of California Santa Barbara and one on Santa Cruz Island. The shore stations provide the entirety of the ship approach into the Channel and on to the Ports of Los Angeles/Long Beach. The boat-mounted AIS provides real-time information to the tagging team on the closest point of approach to the tagged whale and the speed and track of the approaching vessel so that the team can attempt tagging well ahead of the ship approach. Once tagged, the tagged whale's position and surface behavior are monitored and the whale is photographed for individual ID.

Acoustic data collected by the B-Probe and Acousonde are analyzed to determine the presence and spectral characteristics of sounds produced by the whales and the ambient noise level prior to ship approach. Because of high levels of flow noise present in the acoustic tag records it is not always possible to measure the received sound level of the passing ship. During most behaviors the animal is swimming, therefore flow noise is usually high and broadband (150 dB and 0-1,000 Hz). For this reason most analyses are now based on ship proximity and speed, and with reference received levels measured for different ship types from seafloor recorders, rather than on the received level measured by the tag. Close approaches during quiet periods in the tag record do allow for direct measures of received level of the ship on occasion.

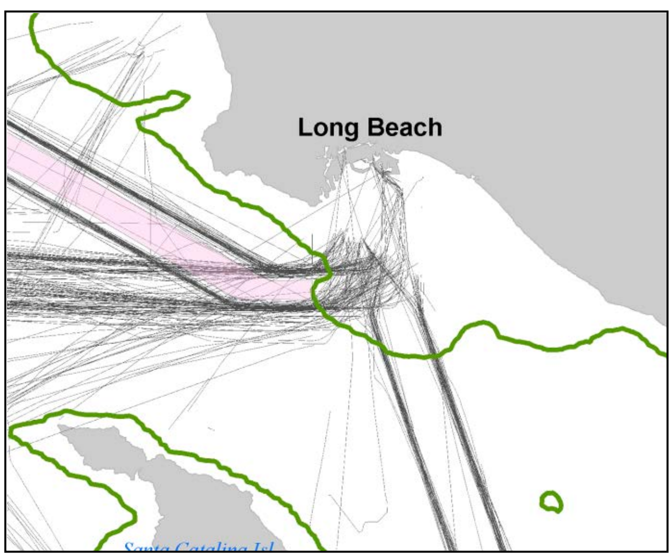

Figure 1. Ship traffic around the ports of LA/ Long Beach. Green line represents the 200m contour. Pink area represents the traffic separation zone between the north and south bound lanes.

Dive depth and body orientation are measured by the sensors on the tag, and additional behavioral variables are derived from the auxiliary sensors, including acceleration, fluke rate, and feeding behavior, such as the presence of vertical or horizontal lunges. These behavioral measures are used to describe swimming mechanics, which may be used to derive energy expenditure (Goldbogen *et al.* 2006). Kinematic data for the tag deployments with a close approach of <1000m prior to the 2011 field season were summarized and presented as deviations around the mean (or anomaly) in previous reports. Behaviors analyzed included dive behavior (duration, number of lunges), surface behavior (durations, number of breaths).

Position data from the MK10 are used to evaluate fine-scale movements of the animals within and near the shipping lanes. Nighttime movements and behavior which cannot be effectively monitored by the research team are recorded on the MK10 for later evaluation of close ship approaches and behavioral changes during this period.

Task 2: Filed testing the new Bioacoustic Probe (Acousonde):
Tags are placed on various cetacean species off Southern California and Hawaii in conjunction with ongoing survey and tagging efforts in those regions. Off Southern California, our efforts are coordinated with visual and acoustic surveys underway as part of the SoCal BRS and our ship strike work (described as part of this report). Acoustic and dive data are analyzed as described above to assess the quality of the data collected by the new tag and to assess vocal and dive behavior of specific species.

WORK COMPLETED

Task1: Blue whale behavioral response study:
Deployments on blue whales in and around the Santa Barbara Channel shipping lanes have been conducted since 2008. Deployments during the current field season are listed in Table 1. During the 2011 season 26 tag deployments of four different types of tags were made on blue whales in and around the shipping lanes near the entrance to the ports of Long Beach and Los Angeles. These were primarily conducted in two dedicated time periods in August and October but included some tag deployments on two days in September conducted during the SOCAL BRS. These provided 142 hours of detailed data on blue whale underwater behavior, including 34 hours with detailed acoustics from the Acousonde, Dtags, and Bprobes and 108 hours with GPS-quality positions including through the night (four of these over 18 hour tracks). The detailed position data will be used to integrate with AIS tracks of ships to identify times, distances and behaviors of whales when ships were very close.

Summary of effort 13-19 August 2011
Over the 7 days of field effort, 14 deployments of four different suction cup tag types were successfully made on blue whales in the LA/Long Beach area (Table 1). In all 7 days of field work, whales were sighted in and around shipping lanes confirming that this region was an important area of potential risk of ship strikes given the high density of ship traffic (Figure 1).

Tags deployed included:

1. Two deployments of DTags (WHOI) on 13 and 14 August in collaboration with Ari Friedlaender (Duke). Both deployments occurred with deployments of MK10F tags.
2. Six deployments of Wildlife Computers Mk10F tags, often in conjunction with other tags.

3. Four deployments of the Acousonde 3B (Greeneridge Sciences)
4. Two deployments of the Bprobe acoustic tag

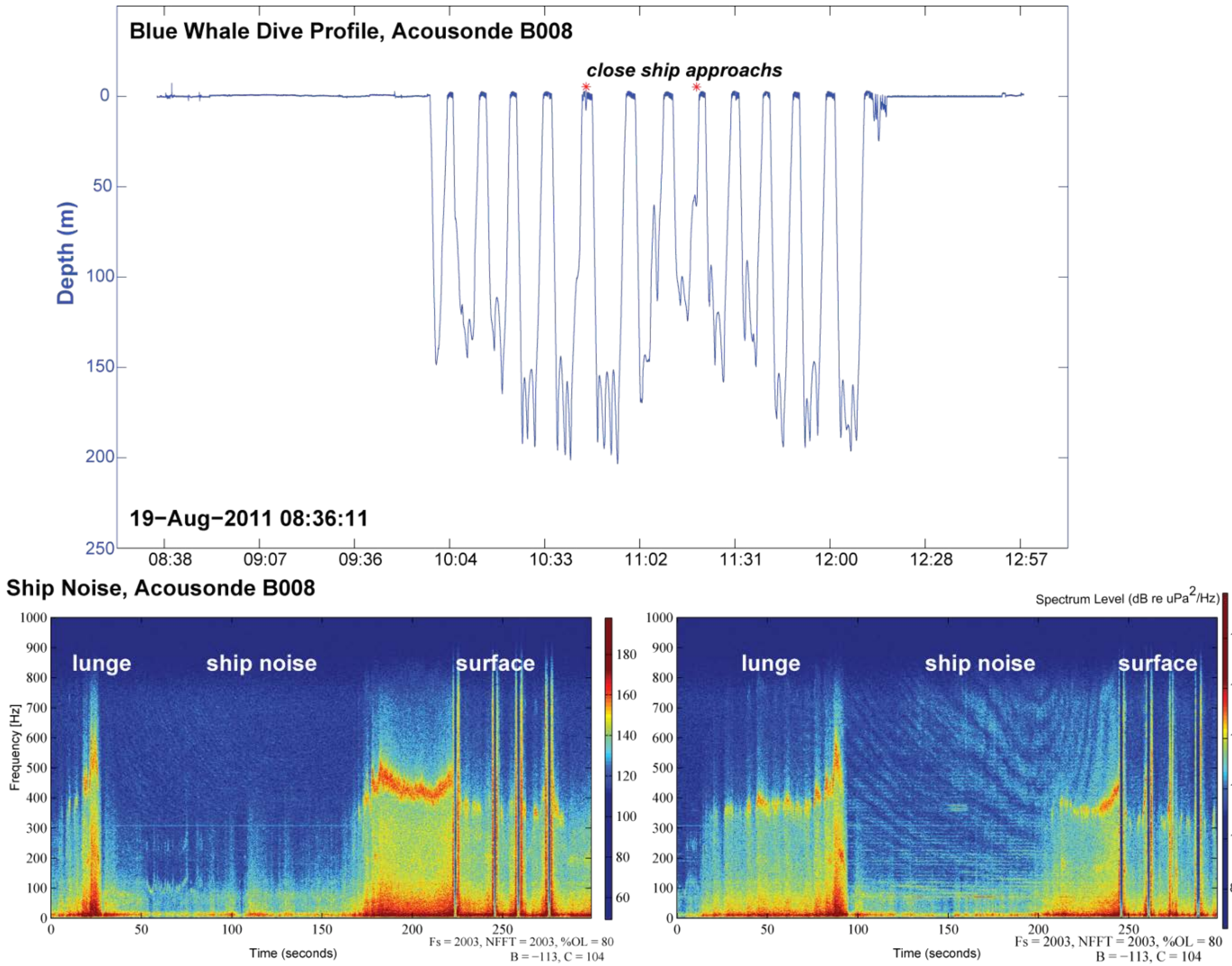

Figure 2. Dive profile for Acousonde B008 deployment on 19 Aug 2011. Tag started sampling at 08:36 was deployed at 09:59 with ship passing close to whale at about 11:20 (noted by *).

Table 1. Deployments of acoustic and GPS tags during 2011.

Date	Time	Tag Type	Tag#	Recover Date	Recover Time	Date off	TagOff Time	H On	Comments
13-Aug-11	15:29	Mk10F	3	14-Aug	8:57	13-Aug	18:51	3.4	Acousonde did not attach
14-Aug-11	11:50	Dtag	230	14-Aug	12:30	14-Aug	12:27	0.6	
14-Aug-11	11:50	Mk10F	1	14-Aug	14:31	14-Aug	14:06	2.3	
14-Aug-11	12:40	Dtag	236	15-Aug	16:07	14-Aug	20:10	7.5	Recovered next day
14-Aug-11	12:40	Mk10F	2	15-Aug	16:35	14-Aug	19:24	6.7	Recovered next day
15-Aug-11	10:49	Acous 3B	B006	15-Aug	11:30	15-Aug	11:28	0.6	Tag failed
15-Aug-11	11:47	Acous 3B	B006	15-Aug	12:47	15-Aug	12:45	1.0	Tag failed
16-Aug-11	10:54	Bprobe	B025	16-Aug	15:10	16-Aug	12:23	1.5	With Mk10
16-Aug-11	10:54	Mk10F	3	16-Aug	15:28	16-Aug	12:04	1.2	With Bprobe
16-Aug-11	10:30	Acous 3B	B008	18-Aug	11:13	16-Aug	20:00	9.5	Picked up 18 Aug 2011
17-Aug-11	8:25	Bprobe	B019	17-Aug	12:30	17-Aug	12:20	3.9	
17-Aug-11	8:25	Mk10F	3	17-Aug	8:54	17-Aug	8:44	0.3	
19-Aug-11	9:59	Acous 3B	B008	19-Aug	12:53	19-Aug	12:15	2.3	Close ship approach
19-Aug-11	14:03	Mk10F	3	19-Aug	14:14	19-Aug	14:09	0.1	
21-Sep-11	7:42	Mk10F	1	22-Sep	17:36	22-Sep	2:16	18.6	Conducted as part of BRS
21-Sep-11	8:13	Mk10F	2	22-Sep	17:00	22-Sep	9:37	25.4	Conducted as part of BRS
21-Sep-11	14:34	Dtag	243	21-Sep	17:12	21-Sep	17:12	2.6	Conducted as part of BRS
21-Sep-11	14:34	Mk10F	3	21-Sep	19:10	21-Sep	15:26	0.9	Conducted as part of BRS
25-Sep-11	16:02	Mk10F	2	25-Sep	18:51	25-Sep	18:18	2.3	Conducted as part of BRS
25-Sep-11	17:54	Mk10F	1	26-Sep	10:53	25-Sep	19:24	1.5	Conducted as part of BRS
03-Oct-11	9:22	Mk10F	3	4-Oct	10:01	4-Oct	4:31	19.1	
03-Oct-11	9:43	Acous 3B	B008	3-Oct	12:48	3-Oct	11:26	1.7	
04-Oct-11	13:41	Acous 3B	B008	4-Oct	17:21	4-Oct	15:18	1.6	
04-Oct-11	13:41	Mk10F	1	6-Oct	11:15	5-Oct	14:55	25.2	Recovered 6 Oct
04-Oct-11	15:01	Acous 3B	B006	4-Oct	17:30	4-Oct	15:39	0.6	
04-Oct-11	15:01	Mk10F	2	4-Oct	17:12	4-Oct	16:21	1.3	

Summary of effort 3-7 October 2011

Effort from 3-7 October 2011 was conducted as a single RHIB operation working from Long Beach Harbor. Effort focused on deployments of Mk10 GPS tags on animals in and around the shipping lanes. Overall weather during this period was not very good so the Mk10 tags were ideal because they provided not only dive data but GPS positions on most surfacings even though when we could not conduct surface observations and monitoring.

Task 2: Field testing the new Bioacoustic Probe

A type 3A Acousonde was delivered in summer of 2010 and was tested on blue whales off Southern California last summer and fall. In early 2011, the new streamlined form factor (3B) became available and two were made available for use during a number of field efforts for testing. Test deployments of the Acousonde 3A and 3B included one week of dedicated tagging effort off Kona, Hawaii in May, 2011, and opportunistic deployments on blue whales during our blue whale ship strike work (Table 2).

Table 2. Deployments of the new Acousonde 3A and 3B during field testing of its sensors and attachment capability. Acoustic and auxiliary data durations are the same for blue whales due to lower acoustic sample rates.

General location	Target species	Date	Tag Type	Tag#	Hrs (acoustic data)	Hrs (auxiliary data)	Comments
Kona, HI	Short-finned pilot whale	6-May-11	3A	A012	2.0	2.3	Power failed after acoustics end
Kona, HI	Spotted dolphin	1183712/10-May-11	3B	B006	8.16	12.0	Filled storage
Long Beach, CA	Blue whale	15-Aug-11	3B	B006	-	-	Tag failed
Long Beach, CA	Blue whale	15-Aug-11	3B	B008	-	-	Tag failed
Long Beach, CA	Blue whale	16-Aug-11	3B	B008	9.5	9.5	
Long Beach, CA	Blue whale	19-Aug-11	3B	B008	2.3	2.3	Close ship approach
Long Beach, CA	Blue whale	3-Oct-11	3B	B008	1.7	1.7	
Long Beach, CA	Blue whale	4-Oct-11	3B	B008	1.6	1.6	
Long Beach, CA	Blue whale	4-Oct-11	3B	B006	0.6	0.6	

RESULTS

Task 1: Blue whale behavioral response study
Behavioral Response based on Kinematic variables
To date we have collected acoustic and high-resolution tracks from four blue whales that were very closely (<200 m) approached by commercial ships within the shipping lanes. Analysis of these records suggests that the close approach does not elicit a strong reaction by the whales; however, the whales do appear to alter their surfacing behavior immediately following the close ship approach. We found a significant increase (>1 standard deviation from the mean of all dives) in the surface time and number of breaths. High-resolution tracks of MK10 tagged aniamls indicate that whales are foraging within the shipping lanes and remain in the area for at least several hours.

During the 2011 field efforts, critical data on the reactions of whales to the close approach of ships was observed on multiple occasions. On 19 August a single blue whale (with an Acousonde tag) and mother/calf pair of blue whales were closely monitored during a very close passage by a container ship and then a high-speed ferry (Figure 2). Previously only four such close encounters had been documented.

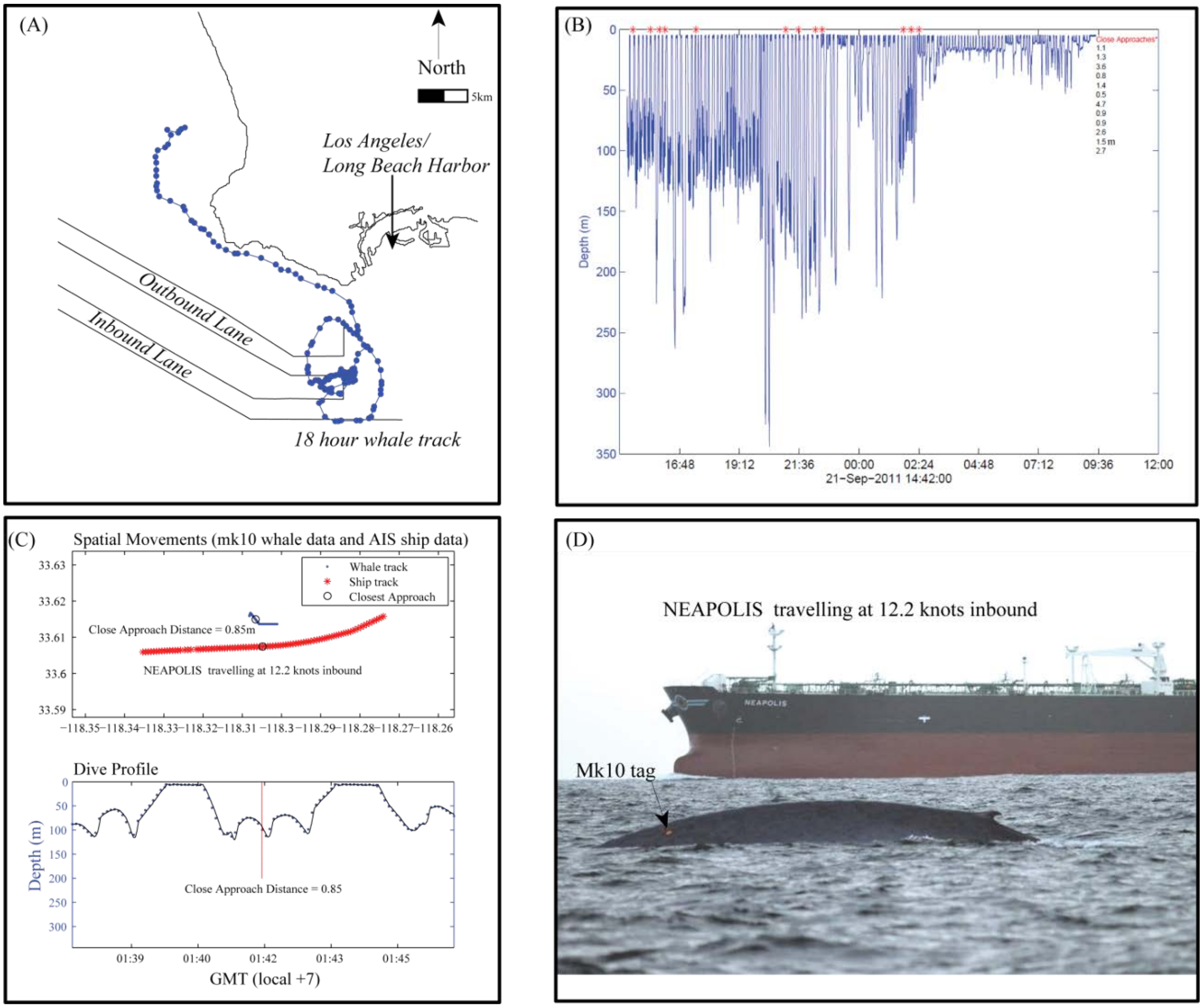

Figure 3. Mk 10 tag deployment on 21 September 2011 and examples of close approaches wit large ships. The tag recorded for 18.6 hours of dive and position data. (A) Interpolated track of blue whale with Mk10 GPS tag points indicated by dots. (B) Dive profile of the whale with red stars indicating close approaches identified from combining mk10 and AIS data. The distances of each close approach are indicated on the right side of the graph. (C) An example of a close approach event, both the spatial movements and the dive profile. (D) Photograph of the close approach shown in (C). The tag is visible on the back of the whale.

Four long term deployments, each of over 18 hours were achieved with the MK10 GPS tags on blue whales in the shipping lanes. These not only provided day-night data on blue whale behaviors (see next section) but also four long records of movements and behavior in the shipping lanes that when matched with ship AIS data allowed evaluation of reactions of whales to ship close approaches.

Using this method of combining MK10 GPS whale track with AIS data additional close approaches were observed and analyzed. As an example, a MK10 tag deployed on 21 September 2011 when processed with AIS data revealed 12 close approaches of less than 5km (Figure 3A-C). One of the close approaches was witnessed by the RHIB and served as verification for this method (Figure 3D).

Preliminary analysis of this data suggests that there is a threshold of spatial response. Only in close approaches less than 1 km did we see a change in the whale movement (Figure 3C). This approach is promising for increasing our sample size of whale response to the close approach of large commercial ships. Future analysis will evaluate changes in kinematic behavior before, during and after the close approaches, similar to previous methods.

Evaluation Of Animals Movement at Night

A total of 25 tag deployments from multiple tags were used to quantify differences in spatial (vertical and horizontal) blue whale behavior given time of day. Dives at night were much shorter and shallower than during the day and transitioned around the time of sunrise and sunset. There is a significant difference in probability of an animal being at a given depth, depending on the hour of the day (Figure 4). The cumulative time spent in waters close enough to the surface to be more vulnerable to ship strikes were higher at night than in the day. During the night hours, there is a high probability (0.9) that animals will be at or shallower than 50 meters; whereas during the day the probabiliy of being at 50m or shallower is much lower (0.5) (Figure 4). A supbset of these tags (only MK10 tags with GPS) will be used to evaluate differences in movement behavior between day and night.

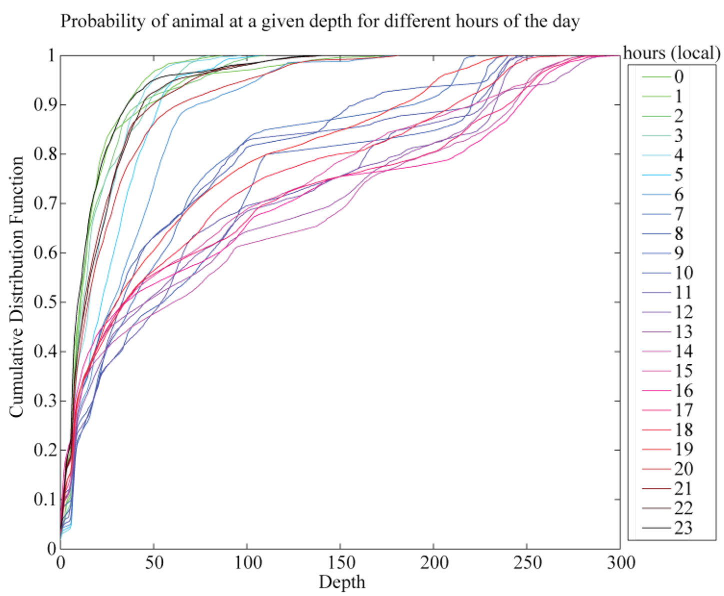

Figure 4. Cumulative distribution functions for the depth of the whales, given different hours of the day. The colors represent the different hours of the day.

Evaluation of noise levels during close approach and identification of close approaches

Our analysis of received sound levels at the whale during close approaches based on tag data (BProbe and Acousdonde 3A) showed some promise. For, example, a comparision of relative received levels at the initial deceleration of a deep foraging dive indicate that when the ship was within about 200 m of the animal, received levels were 15-20 dB higher than when a ship was not present. However, when a ship was 3.5 km from the deep foraging whale, the ship noise was not detected over the flow noise on the tag. This latter result is problematic in that deep foraging dives generally occur 15-20 mintutes apart- enough time for a ship to move 10 km.

Some improvement in ship noise detection was achieved when using the lower-profile Acousonde 3B. Sound levels during different behaviors on the two tag types- 3A (similar profile to BProbe) and 3B- and decreased flow noise was observed (Figure 6). None of the 3B deoplyments lasted into the night, so we were not able to detect additional close approaches based on acoustics.

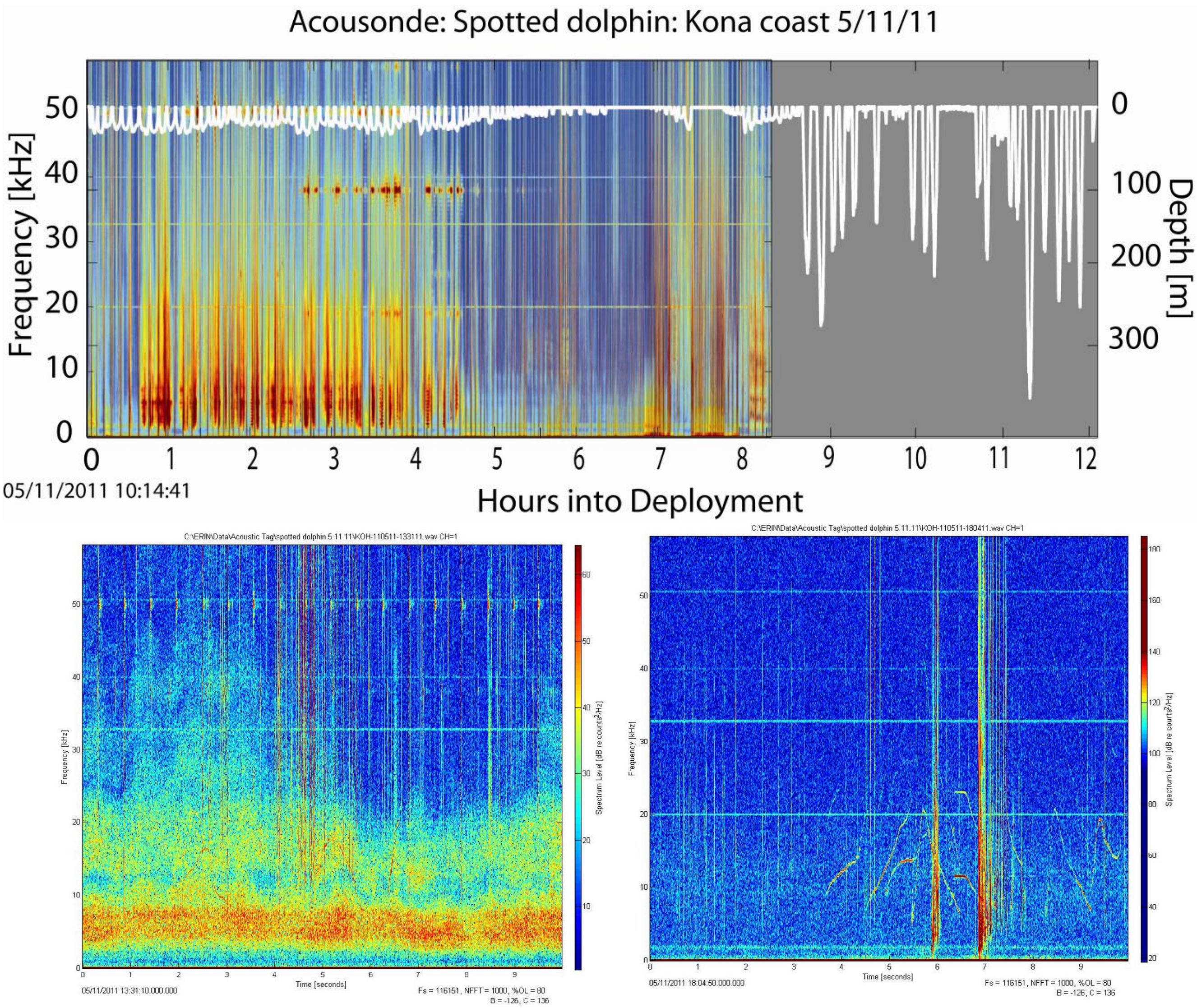

Figure 5. Upper panel: Acoustic and dive record recorded on an Acousonde 3B during deployment on a spotted dolphin off the Kona coast of Hawaii. Acoustic data storage filled approximately 8 hours into the deployment, but collection of auxiliary sensors continued until storage was filled completely. Changes in sound level over the course of the deployment are due to local fishing vessels fishing near and over the solphin shool. Lower left panel: Acoustic record during high boat traffic. Spotted dolphin whistles are largely masked by the vessel noise and echosounder pings are clearly evident in the record. Lower right panel: Acoustic record after vessels have left the dolphin school. The bright broadband areas indicate the tagged animal surfacing. Whistles are heard from nearby dolphins. Lower spectrograms were produced with the same brightness and contrast levels.

Task 2: Field testing the new Bioacoustic Probe (Acousonde)
We have field tested the Acousonde during several missions off Califonria and Hawaii. Off California, one deployment of the 3A was made in 2010 and seven deployments were made of the 3B in 2011, all on blue whales. Several of the 3B attahments were fairly short and may have reflected problems with getting a good attachment with the small form-factor. The 3A provided excellent acoustic and dive data of a calling whale. Data from attachement of the 3B in the shipping lanes provided data on ship noise, as discussed under Task 1.

In May, 2011, two deployments of the Acousonde were undertaken on odontocetes off Kona, HI. The first deployment of the Acousonde 3A on an adult pilot whale collected approximately 2 hours of acoustic data, including clicks and whistles produced by the whales during the deployment. The first deployment of the Acousonde 3B on spotted dolphins was a huge success, as it demonstrated the benefit of the smaller and more streamlined form-factor of the tag. This deployment was the longest known suction cup tag deployment on a spotted dolphin and it collected very valuable data on the vocal and dive behavior of an individual spotted dolphin during intense troll fishing by 8 different fishing boats. The acoustic record of the tag includes not only the sounds of the tagged and nearby dolphins, but also the sounds of the various fishing boats as they passed over the dolphin school (Figure 5). Auxiliary data from both deployments are still being processed and evaluated.

IMPACT/APPLICATIONS

Task 1: Blue whale behavioral response study
With the awarding of a no-cost extension for this work, we anticipate one final year of data integration and analysis on blue whale response to loud ship noise and close ship approach. The results of our tagging and monitoring studies will provide the baseline data needed on sound source (commercial ships and sonars), the behavioral response of blue whales to this source, and an estimate of how these responses may relate to the life functions, such as feeding, migration, and social behavior, of this endangered species.

Task 2: Field testing the new Bioacoustic Probe:
The Acousonde acoustic recording tag includes improved acoustic and auxiliary sensors. The Acousonde is not currently able to sample up to its minimum specification of 232 kHz, but does sample to 116 kHz providing acoustic data up to ~40kHz. Animal orientation can be assessed in 3-dimensions, as well as dive depth, with all sensors capable of 10Hz sampling and some capable of sampling even more often. The new tag should be capable of providing valuable acoustic and dive data from medium to large odontocete cetaceans, a technological and scientific improvement over the previous tag technology. Some tag failures during our testing missions suggest some technical improvements are still needed. In particular, acoustic sampling to 232 kHz is needed.

RELATED PROJECTS

Task 1: Blue whale behavioral response study:
Several agencies and instutions have contributed to the greater goals of this project. Support has been provided by the Channel Islands National Marine Sanctuary who provided time on their vessel R/V Shearwater in 2009, 2010, and 2011. Additional funding has been provided by NMFS Marine Mammal Conservation Division. High-Frequency Acoustic Recorders (HARPs) have been deployed in the and around the Santa Barbara Channel by Scripps Insitution of Oceanography with support from NOAA

Fisheries Acoustics Program. The HARPs have provided valuable data on the spectral and sound level propoerties of individual ships.

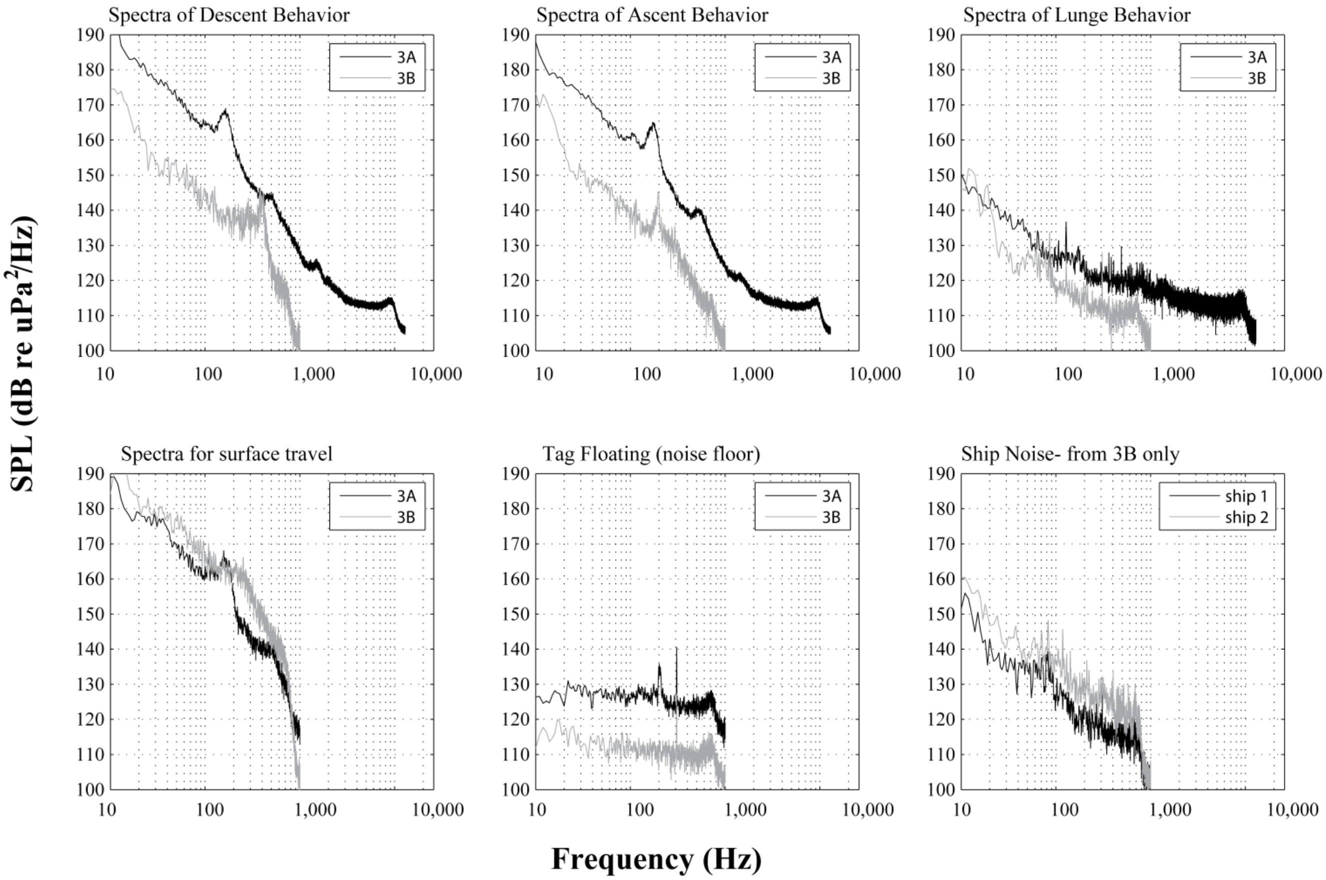

Figure 6a. Comparison of spectral levels measured on different tag types, 3A and 3B. Each plot represents a different behavioral state of when the measurements were taken. Data are 5 second spectral averages in 1 Hz bins.

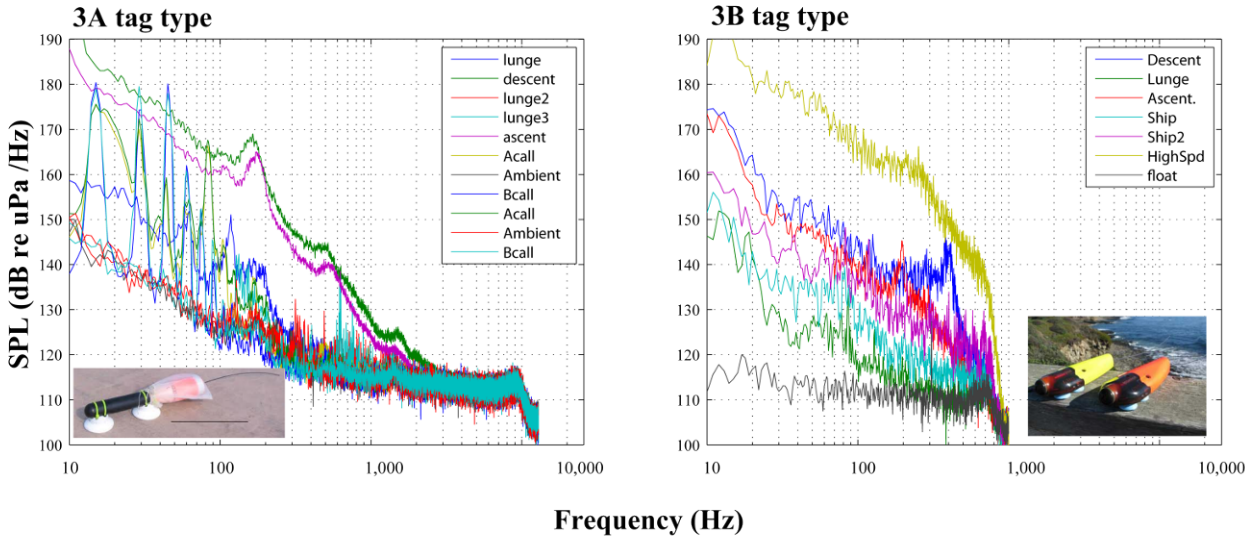

Figure 6b. Comparison of spectral levels measured on different tag types, 3A and 3B. Data are 5 second spectral averages in 1 Hz bins. Image of the 3A tag is actually a Bioacoustic probe, but profile of the tag is similar.

PUBLICATIONS

McKenna, M.F., Calambokidis, J., Goldbogen, J.A., and Oleson, E.M. (in prep, 6 figures, 22 pages) The Response of Deep-Foraging Blue Whales to the Presence of Large Ships.

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McKenna, M.F., Soldevilla, M., Oleson, E., Wiggins, S., and Hildebrand, J.A. (2009) Increased underwater noise levels in the Santa Barbara Channel from Commercial Ship Traffic and their potential impact on blue whales (Balaenoptera musculus). in the Proceedings of the 7th California Islands Symposium, Oxnard, California, February 5-8, 2008. Damiani, C.C. and Garcelon, D.K. (eds) Institute for Wildlife Studies: Arcata, California. CD-ROM. pg 141-149.

Conference Presentations:

McKenna, MF, Calambokidis, J, Goldbogen, JA and, Oleson, EM. (2011). Behavioral Response of Blue Whales to the Presence of Large Commercial Ships. Scheduled talk at the 19th Biennial Conference on the Biology of Marine Mammals.

McKenna, M.F.et al., (2011).Measurements of ship noise and calling behavior on Bioacoustic probes during opportunistic exposure of blue whales to commercial noise. Talk at the 161st Meeting of the Acoustical Society of America, Seattle, WA. * Best student paper award in Animal Bioacoustics.

Goldbogen, J.A, Calambokidis, J, DeRuiter, S.L., Douglas, A.B., Falcone, E., Friedlaender, A.S., Schorr, G., Southall, B.L., Tyack, P.L. 2011. Dynamics of blue and fin whale maneuverability: three-dimensional kinematic analyses for assessing the effects of sound on behavior. Presentation

at the Fourth International Science Symposium on Bio-logging. Hobart, Tasmania, Australia. 14-18 March 2011.

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